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Sea Effects on Grounding Systems An Analytical and Numerical Study

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Introduction

A well designed grounding system can ensure the safe and reliable operation of power systems and the safety of human beings in fault conditions.

The relevance of the problem is increasing with the short circuit fault currents and also with the power systems expansion.

Introduction

In this regard, a correct simulation of grounding systems is fundamental.

It is reasonable to suppose that the sea, with its large volume and its low resistivity, can influence simulation results like GPR and touch and step voltages but it is not evident how and by how much.

Introduction

It is easy to guess that the proximity of the sea reduces GPR, but it is quite surprising to see that despite this, the touch and step voltages tend to increase and that close to the seacoast, an otherwise safe grounding system can be dangerous for people.

Introduction

The study has been extended to the evaluation of the sea effects on insulated pipelines protected with cathodic protection plants.

Simulations are carried out using the program XGSLab™.

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Theory

XGSLab™
is based on the so-called PEEC "Partial Element Equivalent Circuit" method.

XGSLab™
takes into account the following aspects:

Resistive Coupling	Yes
Capacitive Coupling	Yes
Self-Impedance	Yes
Inductive Coupling	Yes
Soil Parameters	ρ, $\varepsilon = f(\omega)$
Propagation Law	$e^{-\gamma r}/r$

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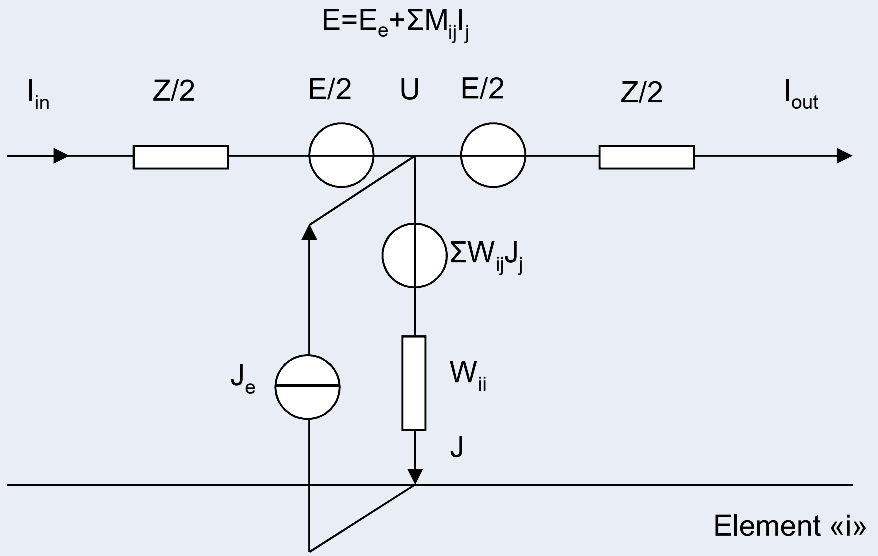
Theory

XGSLab™
divides the conductors network into many elements.

Each element is represented with an equivalent circuit as shown in the figure:



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Theory

The equivalent circuits are governed by a linear system including:

- Topology informations (incidence matrix A)
- Coefficients of potential (matrix W)
- Self and mutual impedances (matrices Z and M)
- Energization (arrays J_e and E_e)

$$\begin{cases} \{U\} = [W]\{J\} \\ \{E_z\} + \{E_e\} = -\left([Z]+[M]\right)\{I\} \\ \{J\} = [A]\{I\} + \{J_e\} \end{cases}$$

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Theory

Formulas for mutual impedances and coefficients of potential with a uniform and infinite extended propagation media are quite simple:

$$M_{ij} = \frac{j\omega\mu}{4\pi} \int_{in}^{out} \int_{in}^{out} \frac{e^{-\gamma r}}{r} dl_i dl_j \qquad W_{ij} = \frac{\rho}{4\pi l} \int_{in}^{out} \frac{e^{-\gamma r}}{r} dl_j$$

The presence of a non-uniform media introduces a strong complexity. The rigorous formulation in the presence of a propagation media with a conducting half space involves Sommerfeld integrals.

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Theory

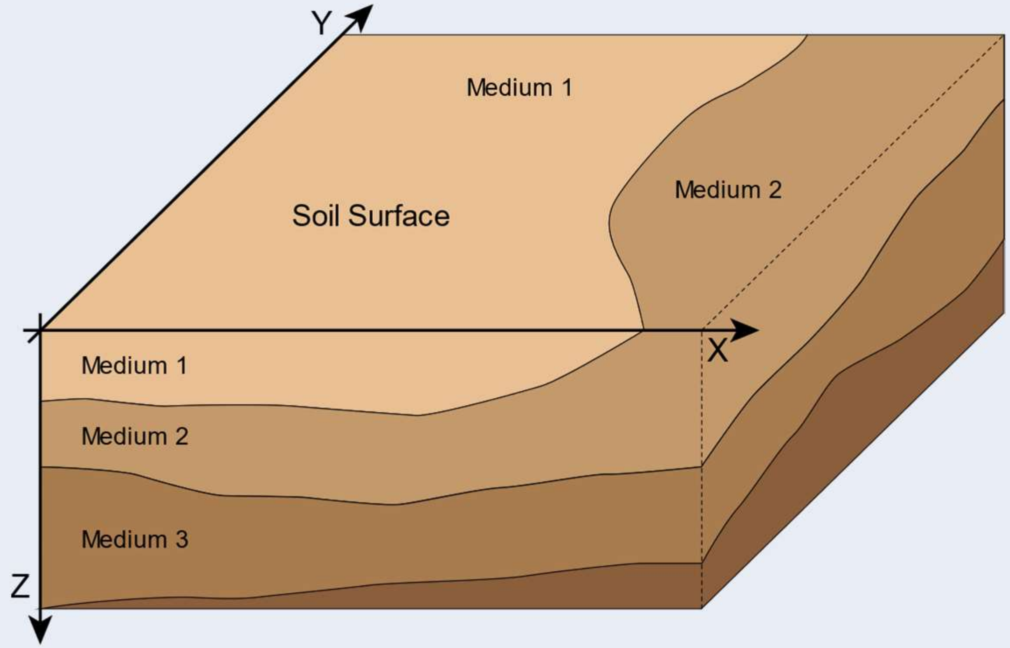
The solution of the linear system provides the distribution of currents, potentials and leakage currents along the conductors network.

From these main results, it is possible to calculate other important distributions such as earth surface potentials and then touch and step voltages, electrical and magnetic fields.

The calculation model described above is suitable for the frequency domain but also for the time domain by using the direct and inverse discrete Fourier transforms.

Models for Soil and Sea

The soil structure in general change both in vertical and horizontal direction and only a 3D map gives an accurate description of real life conditions.



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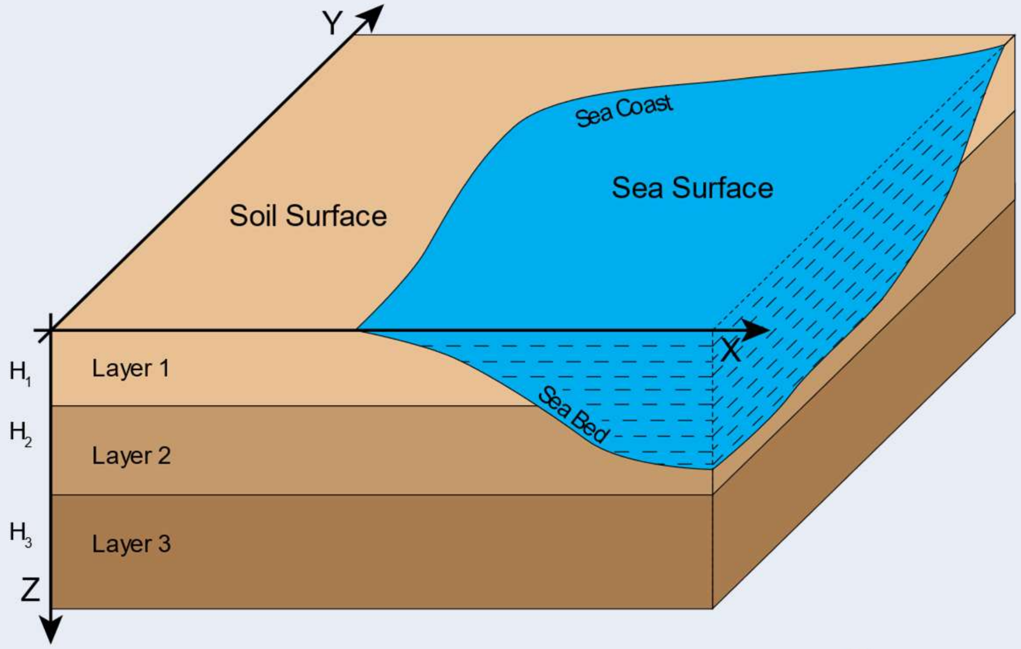
Models for Soil and Sea

XGSLab™ allows you to use uniform, multilayer and multizone soil models (with an arbitrary layers or zones number).

A uniform soil model should be used only when there is a moderate variation in apparent measured resistivity, but for the majority of the soils, this assumption is not valid.

Models for Soil and Sea

Close to the seacoast, soil and sea can be represented with a multilayer soil model and a low resistivity volume representative of the sea.



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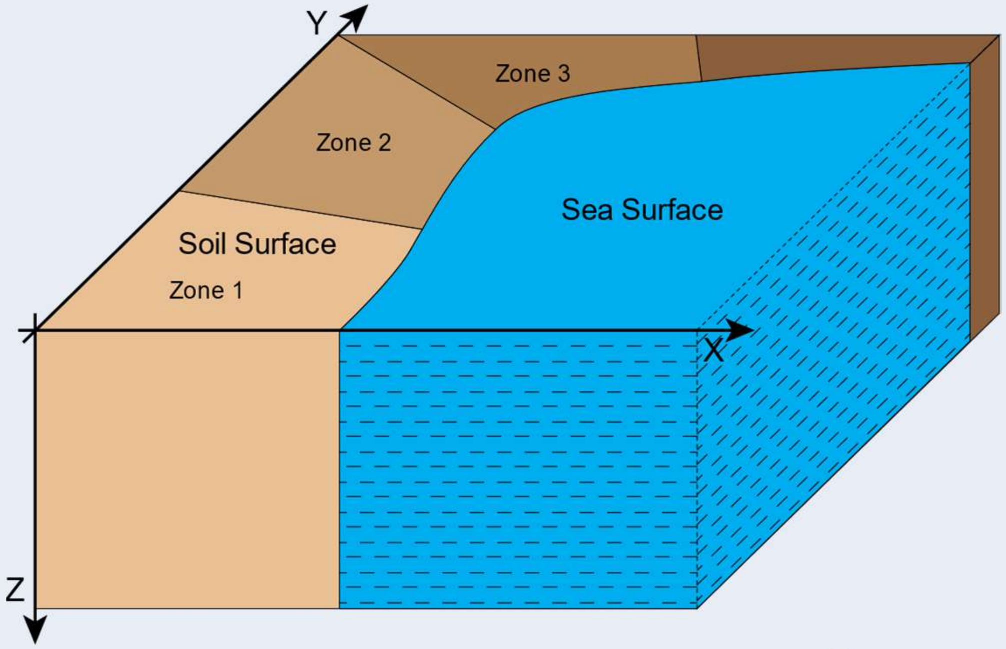
Models for Soil and Sea

In the case of very large systems, the more suitable model is the multizone model, which includes a low resistivity zone representative of the sea.



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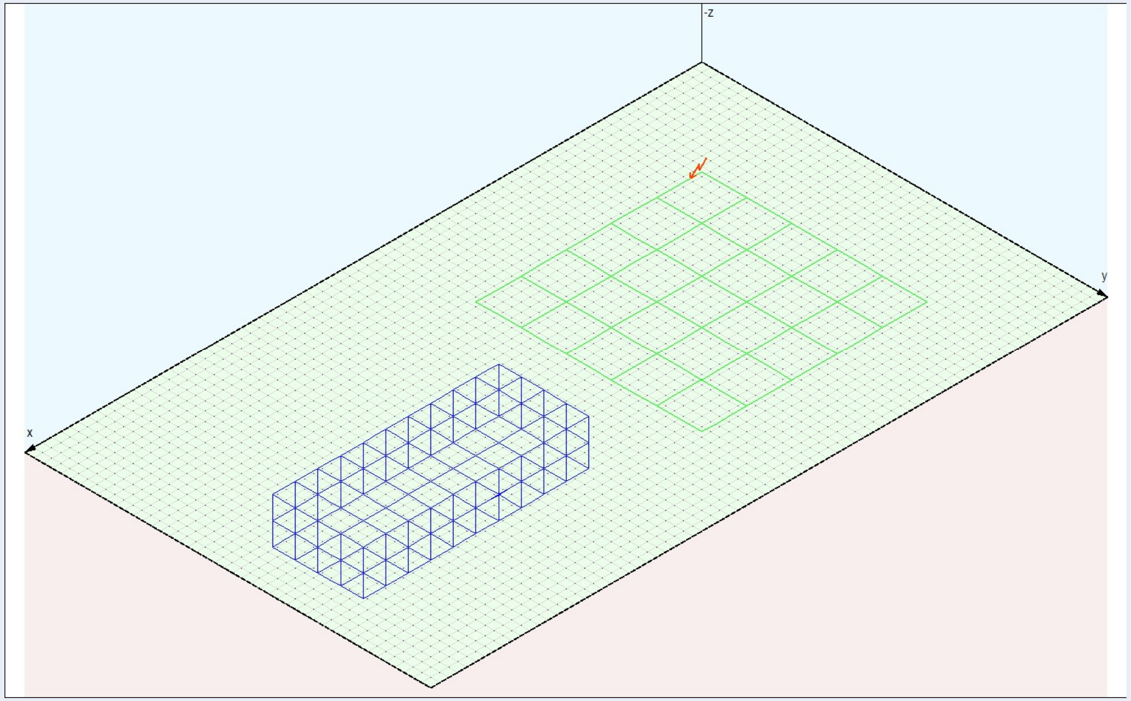
Finite Volume Simulation

The sea will be represented with a very large finite volume — a virtually infinite volume.

The simulation of low resistivity volumes is a propaedeutic scenario.

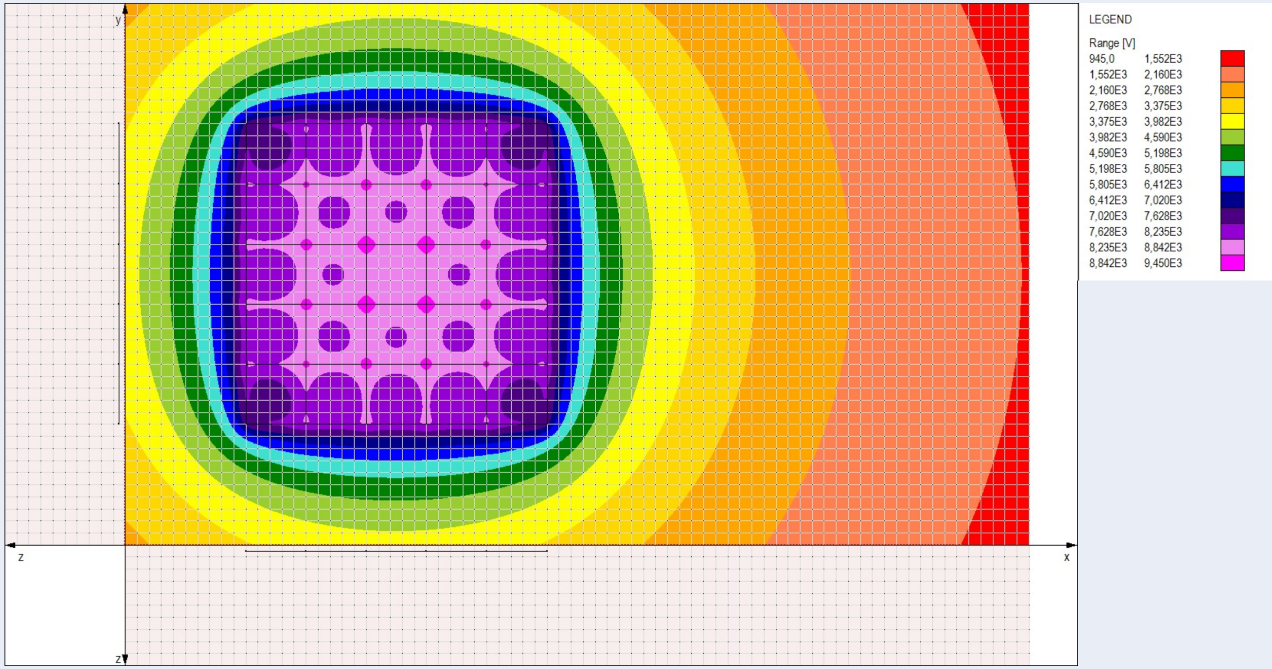
In the figure:

- Green: a grid
- Blue: a low resistivity finite volume



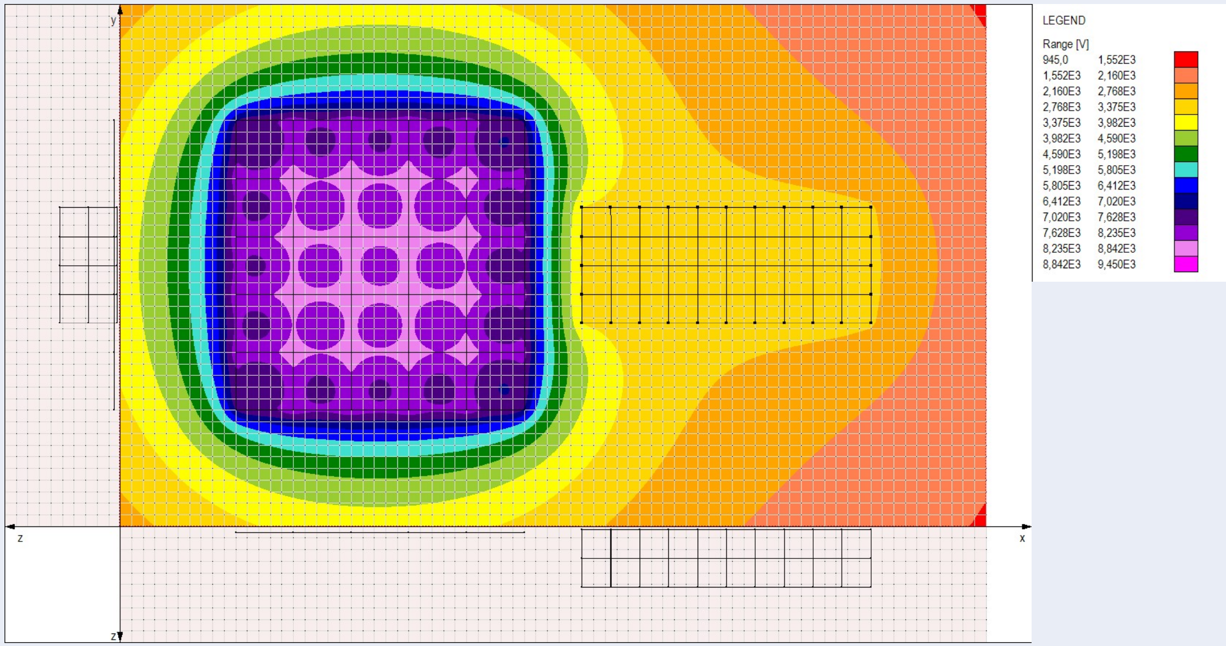
Finite Volume Simulation

A) Soil surface potential distribution without low resistivity finite volume.



Finite Volume Simulation

B) Soil surface potential distribution with low resistivity finite volume with floating potential.



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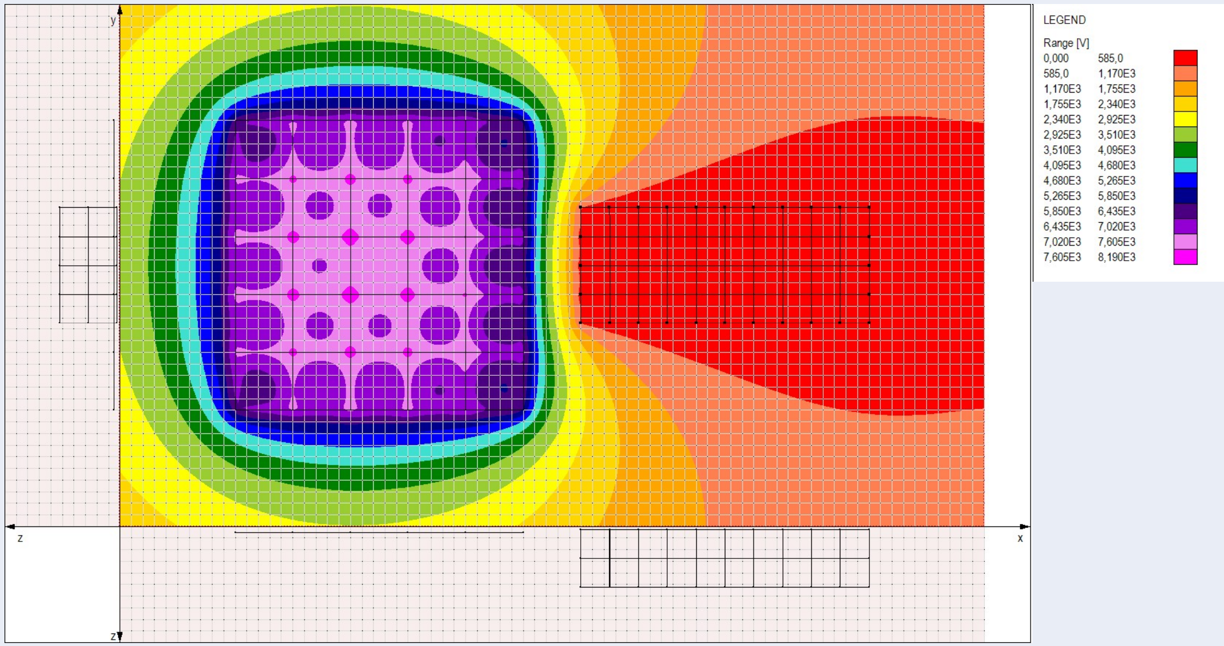
Finite Volume Simulation

C) Soil surface potential distribution with low resistivity finite volume with potential zero.



Finite Volume Simulation

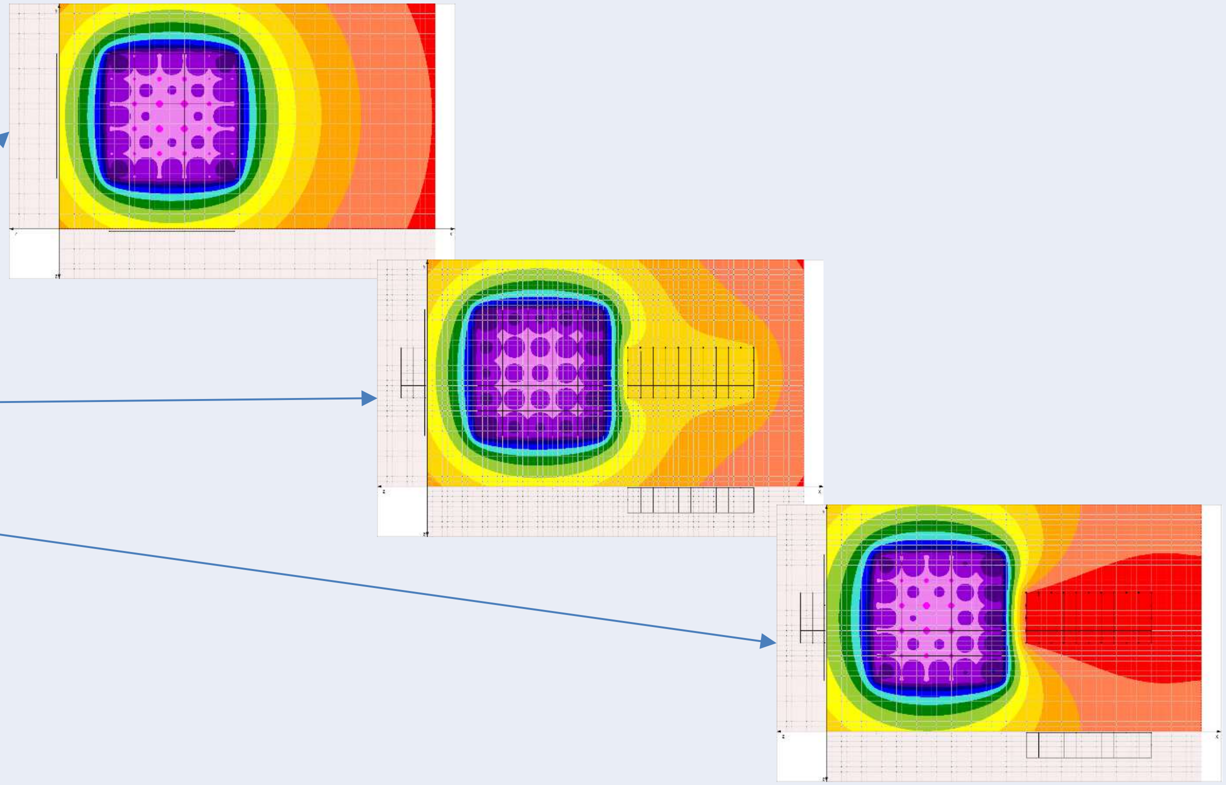
Comparison

GPR:

A) 9575 V

B) 9341 V

C) 8303 V



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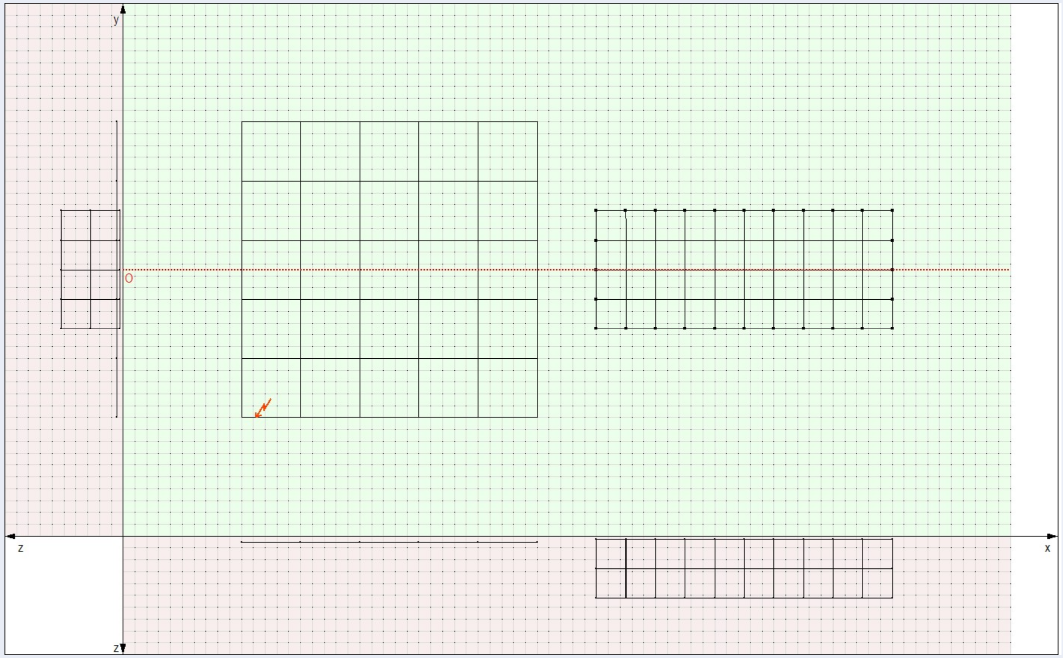
Finite Volume Simulation

Calculation along a line on the soil surface.



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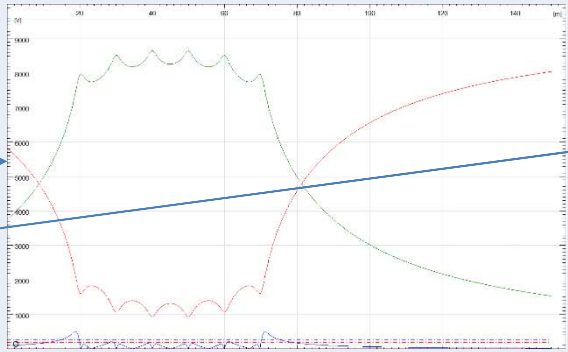
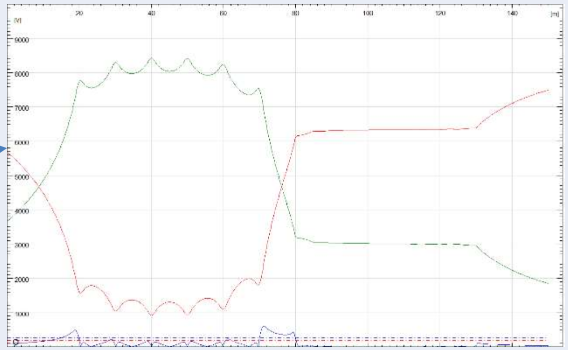
Finite Volume Simulation

Results in cases A, B and C

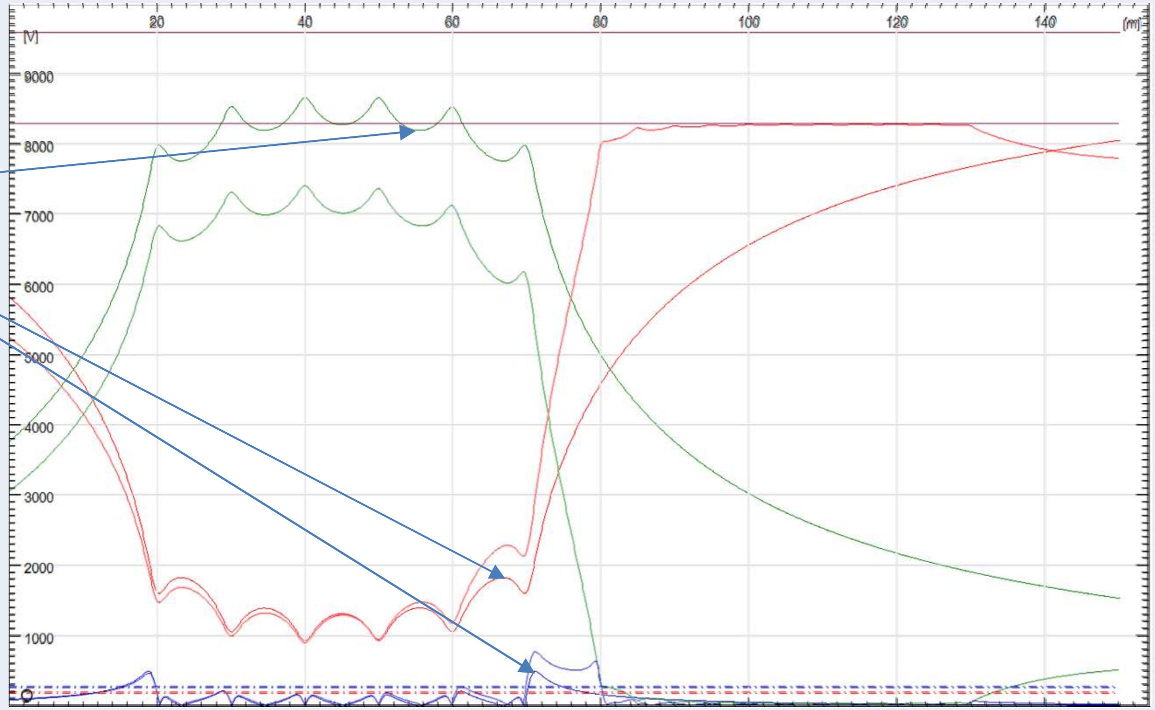




Finite Volume Simulation

Super-
position
results A
and C.

Despite GPR
decreases,
touch and
step voltages
increase!

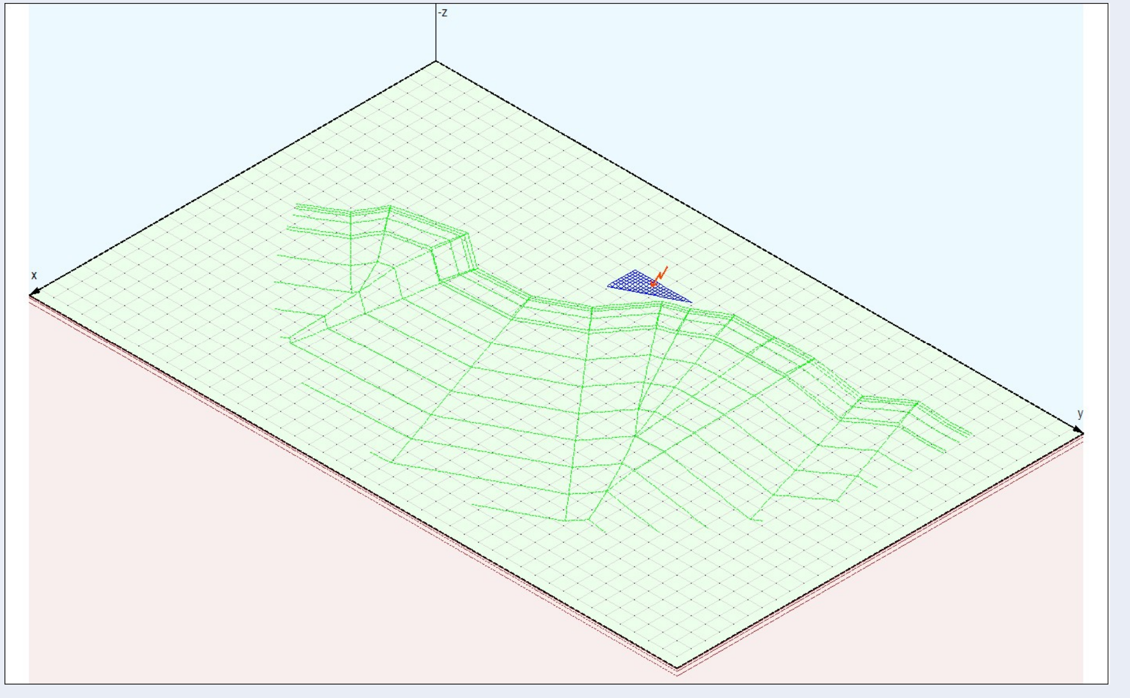


Sea Effects on Grounding Systems

The same «unexpected» result manifests itself considering an infinite volume like the sea.

In the figure:

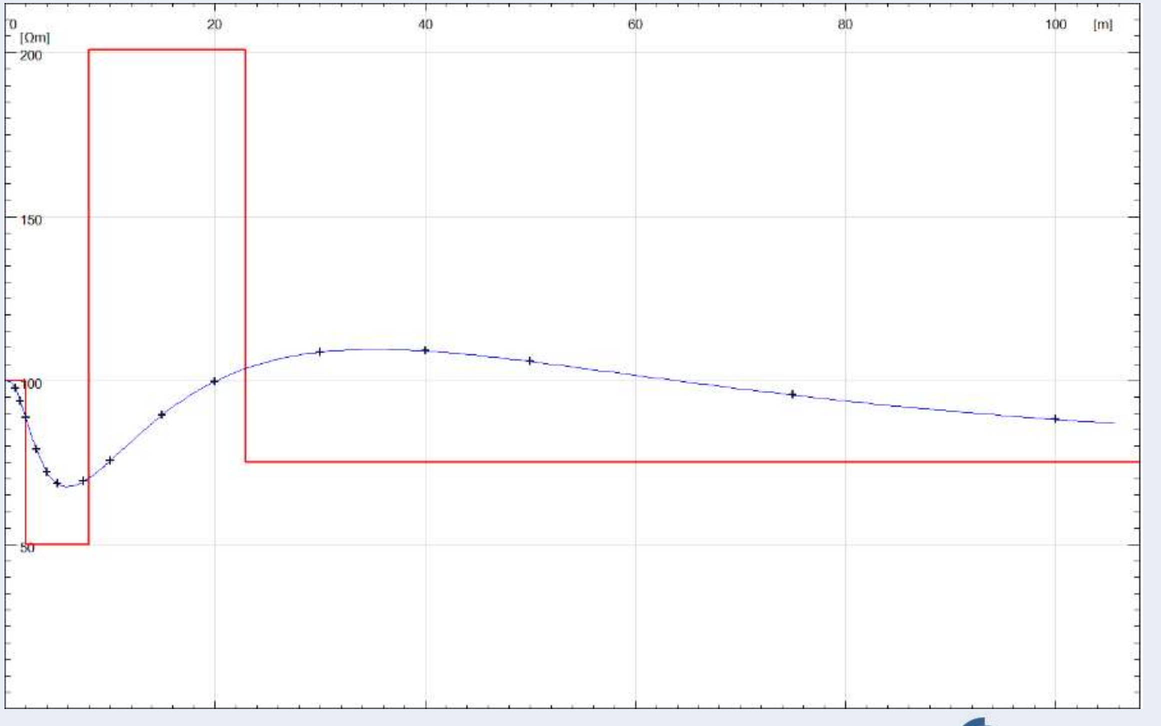
- Blue: a grounding system
- Green: the sea surface and seabed



Sea Effects on Grounding Systems

A four-layer soil model has been considered:

- ρ_1 =100 Ωm
- h_1 = 2 m
- ρ_2 =50 Ωm
- h_2 = 6 m
- ρ_3 = 200 Ωm
- h_3 = 15 m
- ρ_4 = 75 Ωm



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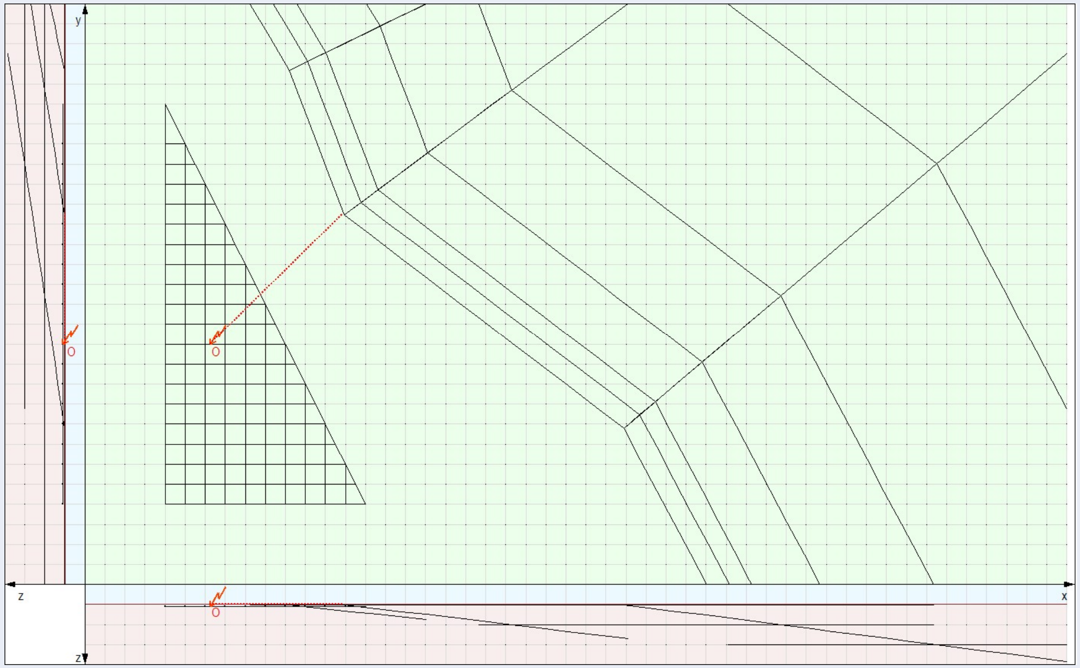
Sea Effects on Grounding Systems

Calculation along a line on the soil surface.



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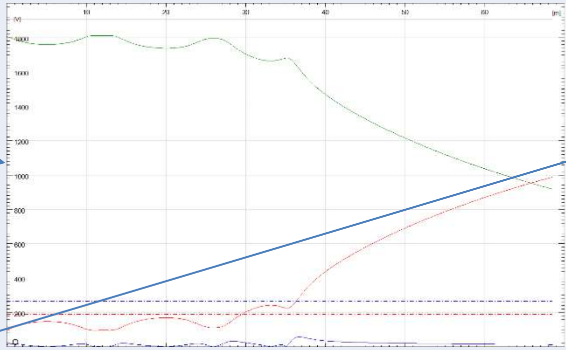
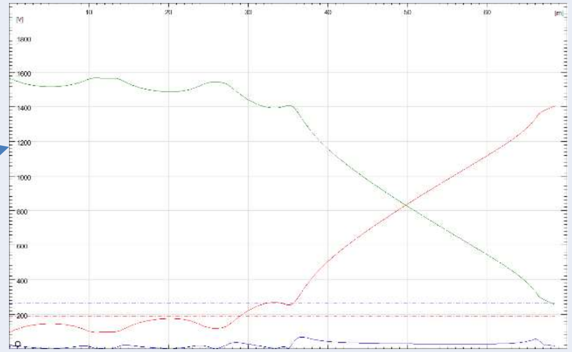
Sea Effects on Grounding Systems

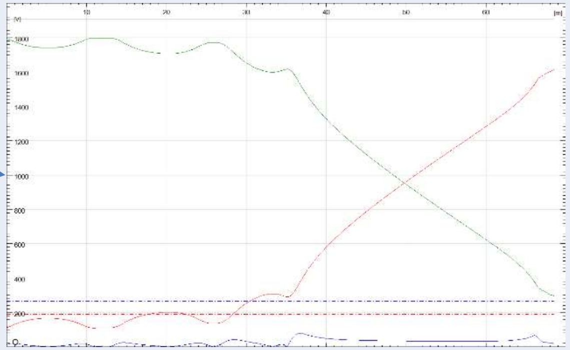
Results in cases A (without sea),

B (with sea and current to earth constant)

and C (with sea and GPR constant).





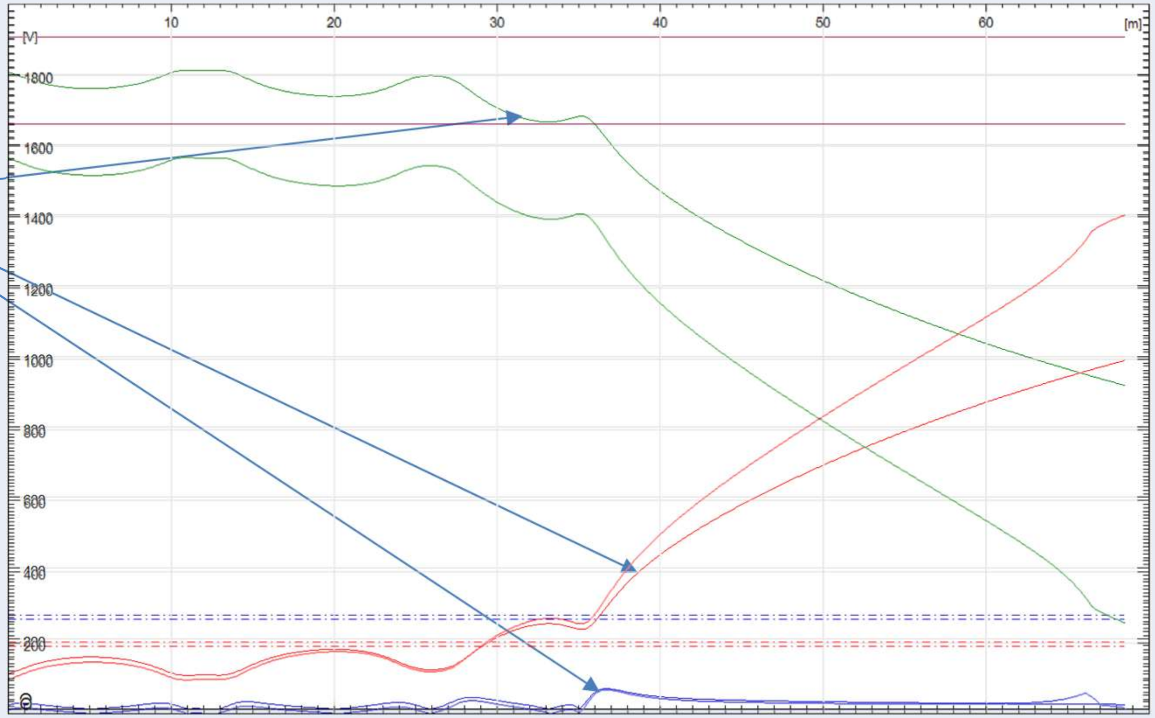


GPR constant means a greather current to earth. This condition is expected if fault current is provided by the same system.

Sea Effects on Grounding Systems

Super-position results A and B.

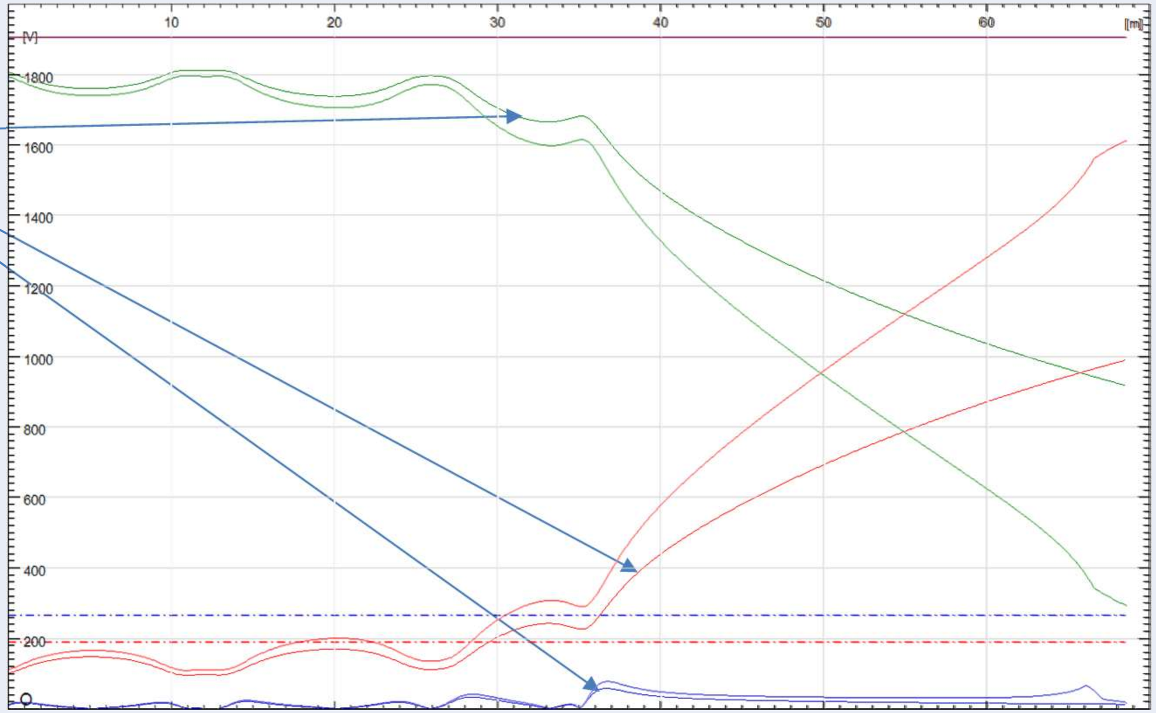
GPR decreases, touch and step voltages increase!



Sea Effects on Grounding Systems

Super-position results A and C.

GPR is constant but touch and step voltages increase significantly!



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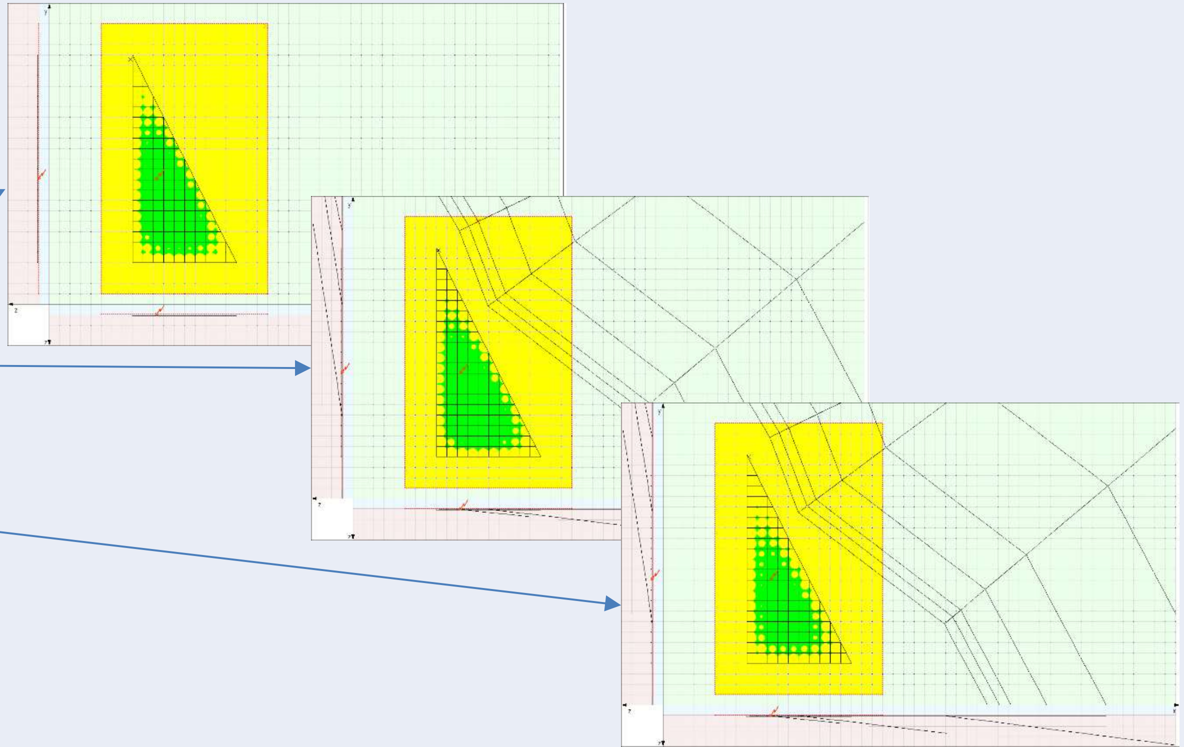
Sea Effects on Grounding Systems

Comparison between safe areas:

A (without sea),

B (with sea and current to earth constant)

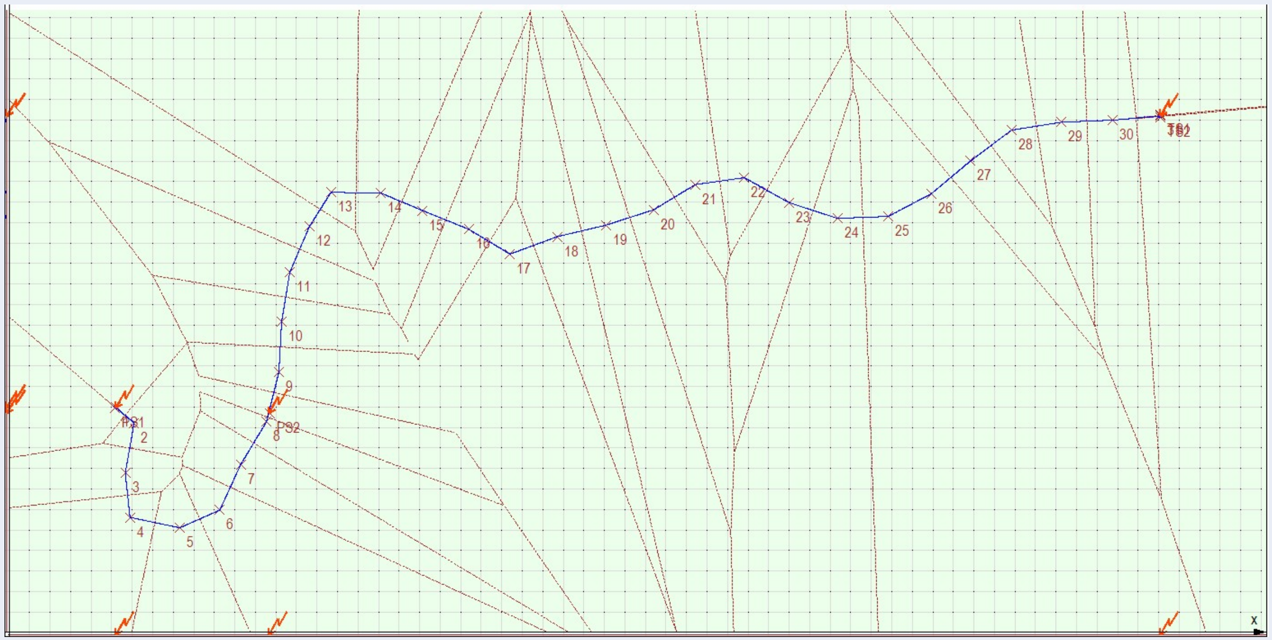
and C (with sea and GPR constant)



Sea Effects on Cathodic Protection

Pipeline to be protected (length 154 km, diameter 2.2 m), multizone soil model (with 31 zones) and anodes (red flashes).

Scenario without sea.



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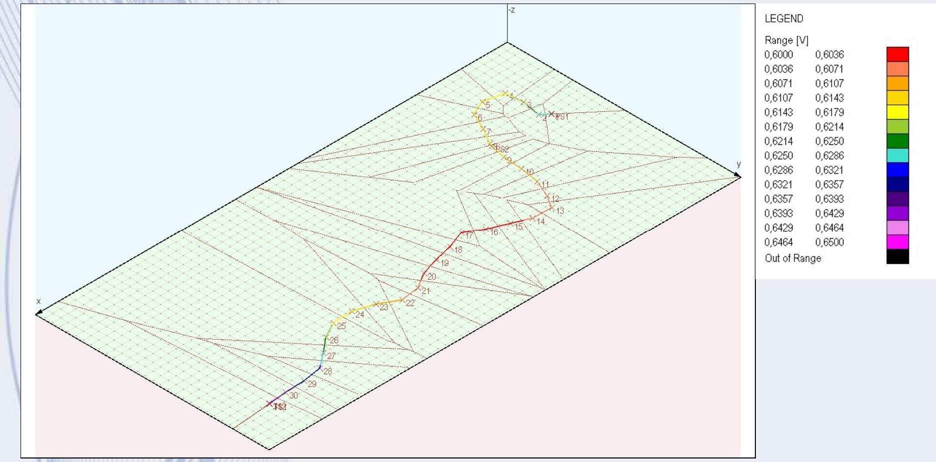
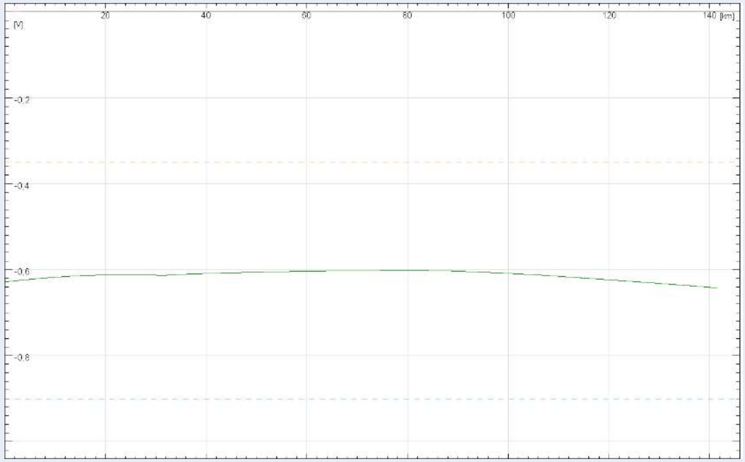
Sea Effects on Cathodic Protection

Operative criterion for cathodic protection in this specific case:
“-900 mV < U < -350 mV”
Potential distribution indicates that the pipeline is correctly protected.





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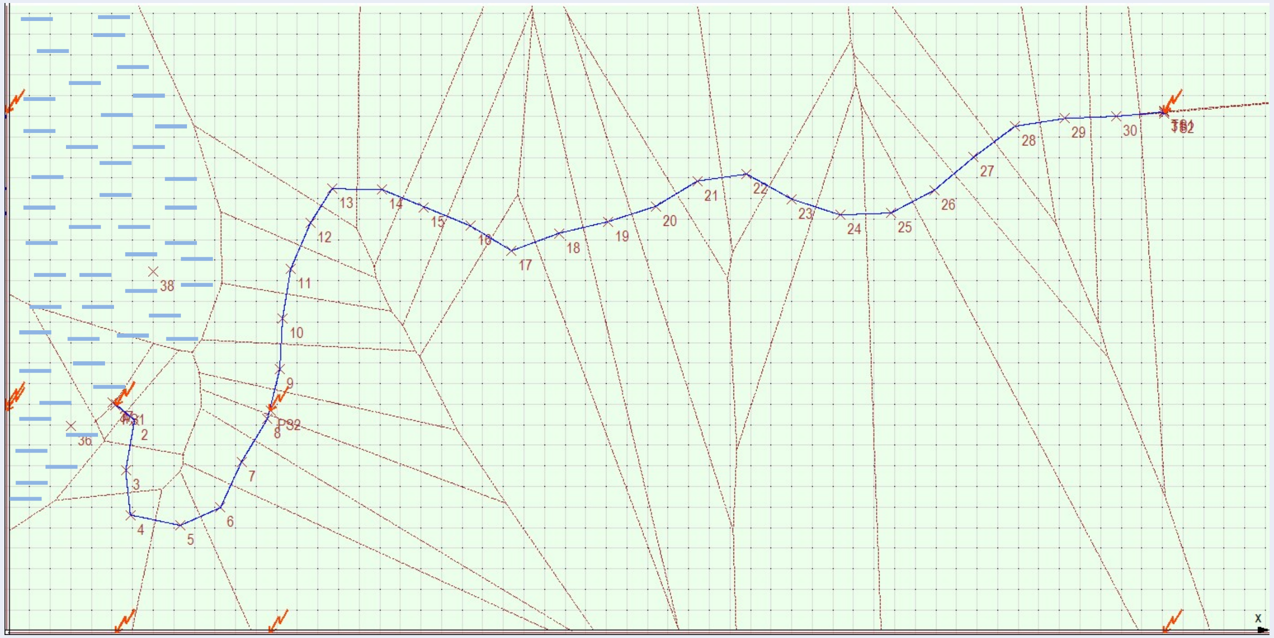
Sea Effects on Cathodic Protection

Scenario
with sea.



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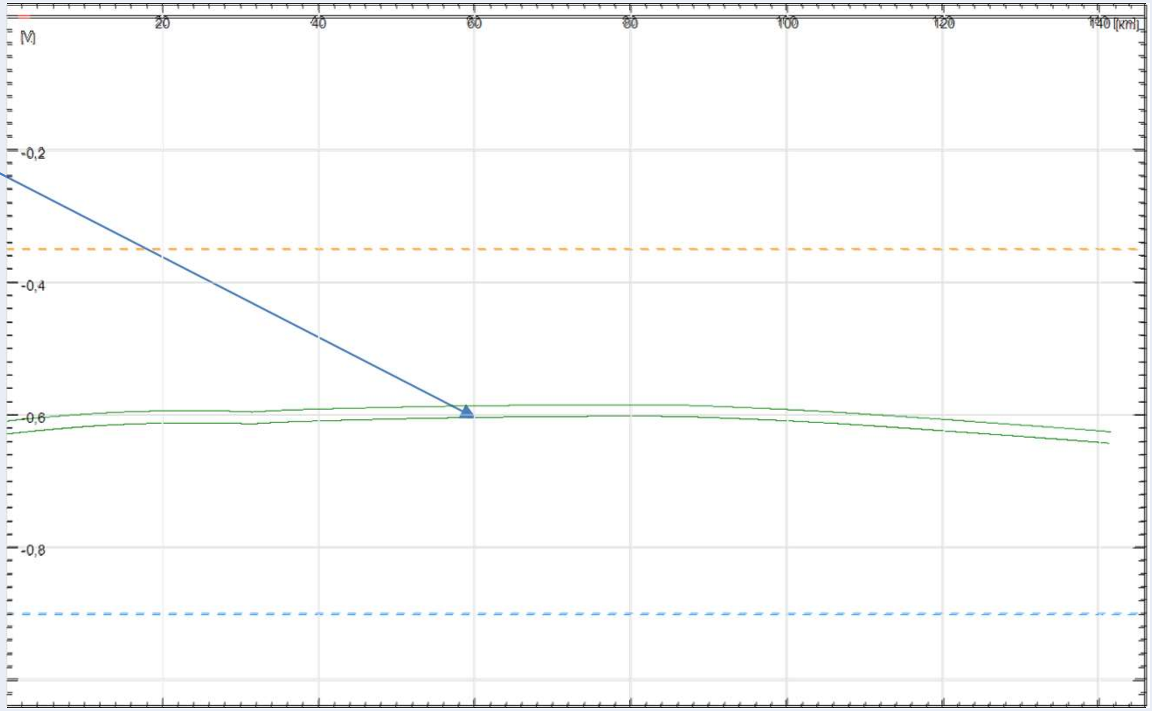
Sea Effects on Cathodic Protection

Super-position results without and with sea.

Potential distribution remains sustantially unchanged!

This because the pipeline is insulated to earth with a high resistivity coating.



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Conclusion

Modern programs like XGSLab™ are able to represent a complex scenario with grounding systems with any shape, buried in soil and represented with a multilayer or multizone model close to the seacoast with an arbitrary shape of the seabed in a very realistic way.

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Conclusion

If the calculation is performed assuming a constant current to earth, the presence of the sea reduces the GPR but surprisingly, it increase touch voltages in all peripheral parts of the grid. If the calculation is performed assuming a constant GPR value, the increasing of the touch voltages can be relevant.

The effects of the sea in the step voltages are less evident and anyway step voltages are seldom dangerous.

Conclusion

The study confirms the importance of a realistic simulation of the sea effects when a grounding system lies close to the seacoast.

Conversely, sea effects are substantially negligible on potential distribution along an insulated pipeline protected with a cathodic protection system.

Thanks for your attention.